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Forest Health Protection

Pacific Southwest Region
Northeastern California Shared Service Area

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To: District Ranger, Doublehead Ranger District, Modoc National Forest

Subject: Entomology input into the Caldera project at Medicine Lake (FHP Report NE15-03)

Summary

This report describes current lodgepole pine stand conditions, recent mountain pine beetle-caused tree mortality and discusses management alternatives within the proposed Caldera project at Medicine Lake, Modoc National Forest. Mountain pine beetle activity within the project area has been monitored by Forest Health Protection (FHP) through aerial survey since 1996 and on the ground site visits since 2011. The objectives of these site visits were to assess stand conditions, determine the level of mountain pine beetle-caused tree mortality and consider management options that would protect high-value lodgepole pine in the short-term and treatments that would improve forest health and resilience over the long-term.

Key points:

- Most of the lodgepole pine stands within the Medicine Lake caldera contain several hundred trees per acre as well as high numbers of larger diameter trees (>9" dbh). Many of these stands are considered to be highly susceptible to widespread mountain pine beetle-caused mortality.
- Mountain pine beetle-caused lodgepole pine mortality reached outbreak levels within portions of the Medicine Lake caldera between 2005 and 2014 resulting in thousands of dead trees, including high-value trees within campgrounds and day-use areas. Similar lodgepole pine stands within the northern California and south-central Oregon region have recently experienced severe mountain pine beetle outbreaks, resulting in significant losses of larger diameter trees. Examples include the Warner Mountains (Modoc and Fremont-Winema National Forests), Shovel Creek (Klamath National Forest), and Campbell Lake (Fremont-Winema National Forest).
- Reducing the negative impacts of future mountain pine beetle activity within the Medicine Lake caldera will require the use of silvicultural treatments that reduce the number of larger diameter trees while creating heterogeneity in tree size, age and density across the landscape.

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Medicine Lake Site information

Approximately 5,300 acres of lodgepole pine (*Pinus contorta* var. *murrayana*) exists within the Medicine Lake basin (the caldera) which lies to the southwest of Lava Beds National Monument (T43N, R3E, Sections 1-3 and 10-14) at elevations ranging between 6,600 and 7,600 feet. Precipitation for the site averages between 30 – 50 inches per year with most areas receiving < 40" per year. The lodgepole pine stands in this area are mostly pure but some stands are mixed with various levels of red fir (*Abies magnifica*), western white pine (*Pinus monticola*) and/or mountain hemlock (*Tsuga mertensiana*). The percentages of these other species are greater where soil is well developed and at higher elevations above cold air sinks.

Forest stand conditions at Medicine Lake

Based on Modoc National Forest stand exam data, most lodgepole pine (LPP) dominated stands within the Medicine Lake caldera are overly dense with high numbers of larger diameter trees (> 9" dbh). Several stands contain > 100 larger diameter LPP/acre and some stands contain up to 168 larger diameter LPP/acre. Medicine Lake stand data also depicts high LPP density in terms of basal area and SDI (stand density index) (Table 1). One-acre plots established by the Pacific Northwest Research Station (PNW) and FHP within a portion of the Medicine Lake caldera contained an average of 151 LPP per acre ≥ 9" dbh (range 111 - 185). Additional surveys of LPP stands around Medicine Lake by FHP found an average of 106 LPP per acre ≥ 8" dbh (range 38 - 161).

Table 1. Medicine Lake stand data collected by Modoc National Forest.

Stand #	TPA	BA	SDI	QMD	LPPA > 9"	BA > 3"	Pine BA > 6"	% Suitable Host
6100016Agg1	698	127	265	7.2	102	123	104	85
6100025	1512	75	188	4.5	73	70	67	96
6100040	668	171	350	7.5	121	169	135	80
6100110	639	174	337	8.8	141	173	153	88
6100120Agg2	579	270	511	9.2	167	267	260	97
6100130Agg1	997	156	349	6.1	88	152	91	60
6100140Agg1	464	135	252	9.5	115	134	125	93
6100150Agg1	846	126	282	6	78	122	107	88
6100170Agg1	1512	206	488	5.2	113	197	142	72
6100170Agg2	554	189	373	8.3	137	187	170	91
6100190	647	209	425	7.7	168	205	179	87
6100270Agg1	444	260	452	11.5	64	259	72	28
6100400Agg1	619	111	232	7.2	87	110	101	92
6110011Agg1	3115	25	88	1.8	6	12	8	67

(TPA=trees per acre, BA=basal area, SDI=stand density index, QMD=quadratic mean diameter, LPPA=Lodgepole pine per acre)

Susceptibility of lodgepole pine to mountain pine beetle-caused mortality

Lodgepole pines that are ≥ 8" dbh are considered to be preferred hosts for mountain pine beetle (MPB) (Gibson et al 2009, Amman et al 1977). The preference for large diameter trees by MPB and the importance of large diameter LPP in outbreak dynamics is also described by several authors (see Progar et al 2013). Some of the possible explanations for large tree preference are that large trees have thicker bark that can protect larvae from winter cold and parasitic wasps and may also contain thicker phloem that increases brood survival and fitness. It is also suggested

that large diameter trees attract pioneering MPB into stands and are necessary to sustain outbreaks.

The importance of larger LPP to MPB population dynamics is also highlighted by various stand hazard/susceptibility rating systems. Lodgepole pine that are ≥ 9" dbh are considered important for the stand hazard rating system developed by Eglitis (2015) and validated by Simpson and Maffei (2009). LPP >9" dbh are also important for suggested stocking levels developed by Cochran et al (1994) and Cochran and Dahms (2000). Lodgepole pine ≥ 6" dbh are considered an important threshold for susceptibility ratings developed by Shore and Safranyik (1992). PNW and FHP plot data at Medicine Lake also revealed higher percent mortality for LPP > 9" dbh in MPB-infested stands (Figure 1).

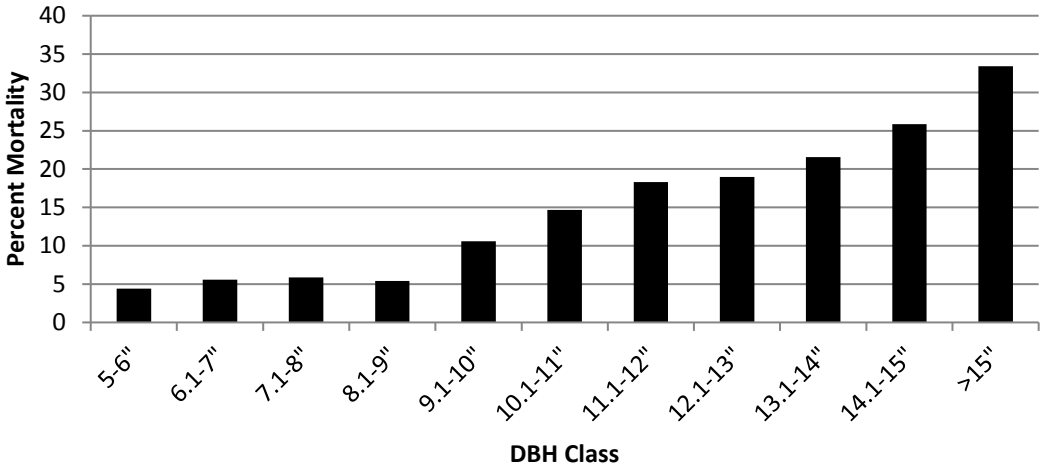


Figure 1. Percent LPP mortality by diameter class in mountain pine beetle-infested plots.

Stand basal area and SDI are also important indicators of MPB susceptibility when stands contain susceptible host trees. Many hazard/susceptibility rating systems for lodgepole pine stands use 80 sq.ft./acre of basal area as a threshold for moderate and 120 sq.ft./acre for high hazard/susceptibility (Randall and Bush 2010, Randall and Tensmeyer 2000, McGregor 1987, Mata 2003, Gibson 1989). Some describe hazardous LPP stand conditions as having >80 sq.ft./acre of basal area, being older than 80 years and average diameter >8 inches (Flanagan 2008). In general, reducing and limiting LPP density to 80 sq.ft./acre is a common recommendation given to land managers by FHP and State Agencies (e.g. Cluck 2006 and 2011, Colorado State Forest Service, Montana Department of Natural Resources and Conservation). Cochran et al (1994) and Cochran and Dahms (2000) recommend SDI 170 as the maximum stocking for lodgepole pine in Oregon when stands contain trees > 9" dbh. A review of Forest Inventory and Analysis plot data for California revealed that SDI 200 may be an appropriate stocking target for lodgepole pine to keep the probability of mortality below 20% (Landram 2005).

Susceptibility of lodgepole pine stands at Medicine Lake

Most LPP stands at Medicine Lake are considered to be highly susceptible to MPB-caused mortality based on several rating systems (Table 2). Variables in most of these systems include stand age, elevation and latitude, average stand diameter, one or more measures of stand density and percent LPP relative to other tree species. Landram (2005) and Cochran (1994 and 2000) are

not necessarily rating systems but suggested stocking levels that reduce the chance of MPB-caused mortality. The Shore and Safranyik (1992) rating system was developed in the northern Rocky Mountains of British Columbia and is considered to have wide geographic applicability (Shore et al 2000). It has also been incorporated into the US Forest Service's Forest Vegetation Simulator (FVS) which facilitates analysis of stand exam data. Medicine Lake stand data related to Shore and Safranyik susceptibility ratings are displayed in Table 3.

Table 2. Summary of Medicine Lake lodgepole pine stand ratings

Stand #	Eglitis 2014	Shore and Safranyik 1992	Randall and Tensmeyer 2000	BA 80 - 120 = Moderate; BA >120 = High*	USFS Region 5 Risk Model 2012	Amman 1977	Landram 2005 (200 SDI)	Cochran 1994 and 2000 (SDI 170)
6100016Agg1	High	High	High	High	Moderate	High	Above	Above
6100025	Moderate	Moderate	Low	Low	Moderate	High	Below	Below
6100040	High	High	High	High	High	High	Above	Above
6100110	High	Moderate	High	High	High	High	Above	Above
6100120Agg2	High	High	Low	High	High	High	Above	Above
6100130Agg1	Moderate	Moderate	High	High	High	High	Above	Above
6100140Agg1	High	Moderate	Moderate	High	Moderate	High	Above	Above
6100150Agg1	Moderate	High	High	High	Moderate	High	Above	Above
6100170Agg1	High	Moderate	Moderate	High	High	High	Above	Above
6100170Agg2	High	High	High	High	High	High	Above	Above
6100190	High	High	High	High	High	High	Above	Above
6100270Agg1	Low	Low	Low	High	High	High	Above	Above
6100400Agg1	Moderate	Moderate	Moderate	Moderate	Moderate	High	Above	Above
6110011Agg1	Low	Low	Low	Low	Low	NA	Below	Below
*Various sources (Randall and Tensmeyer 2000, McGregor 1987, Mata 2003, Gibson 1989)								

Table 3. Medicine Lake stand susceptibility based on Shore and Safranyik 1992.

Stand #	Age >10"	Age Factor	TPH > 3"	Density Factor	Location Factor	Susceptibility Score	Susceptibility Rating*	Potential % BA Killed by MPB
6100016Agg1	190	1	820	1	1	85	High	57
6100025	121	1	333	0.5	1	48	Moderate	33
6100040	103	1	1005	1	1	81	High	55
6100110	132	1	748	0.5	1	44	Moderate	30
6100120Agg2	109	1	813	1	1	97	High	66
6100130Agg1	99	1	1015	1	1	62	Moderate	42
6100140Agg1	117	1	595	0.5	1	47	Moderate	32
6100150Agg1	122	1	872	1	1	85	High	58
6100170Agg1	98	1	1870	0.8	1	58	Moderate	39
6100170Agg2	84	1	1062	1	1	91	High	62
6100190	137	1	1270	1	1	87	High	59
6100270Agg1	82	1	699	0.5	1	14	Low	9
6100400Agg1	115	1	590	0.5	1	46	Moderate	31
6110011Agg1	128	1	158	0.1	1	7	Low	5

*Shore and Safranyik stand susceptibility (0 to 100) arbitrarily subdivided into low (0 to 35), moderate (36 to 70), and high (71 to 100) classes by Mata et al 2003.

The Eglitis rating system (Eglitis 2015) developed for central Oregon is based on the number of larger LPP per acre. Mature LPP stands are the most susceptible to MPB-caused mortality and are typically characterized by having > 100 trees >9" dbh/acre. Stands that exceeded this threshold experienced the highest levels of mortality during the recent MPB outbreak in central Oregon (Simpson and Maffei 2009). Although not explicitly described in this system, the susceptibility rating of stands that contain 70 - 99 LPPA >9"dbh could be considered moderate and may reach a high rating in a few years as 6-8" dbh trees put on radial growth. These stands would also be considered at risk should mountain pine beetle populations reach outbreak levels in any adjacent stands. Data from the recent MPB outbreak in Oregon suggest that stands with lower susceptibility that were within 1500m of outbreak areas experienced high levels of mortality (Eglitis 2015). The advantage of the Eglitis rating system is that it was developed close to the Medicine Lake area for the same variety of LPP (var. *murrayana*). Medicine Lake stand data related to the Eglitis susceptibility ratings are displayed in Table 4.

Table 4. Medicine Lake stand susceptibility based on thresholds developed in Oregon by Eglitis 2015 and validated by Simpson and Maffei 2009

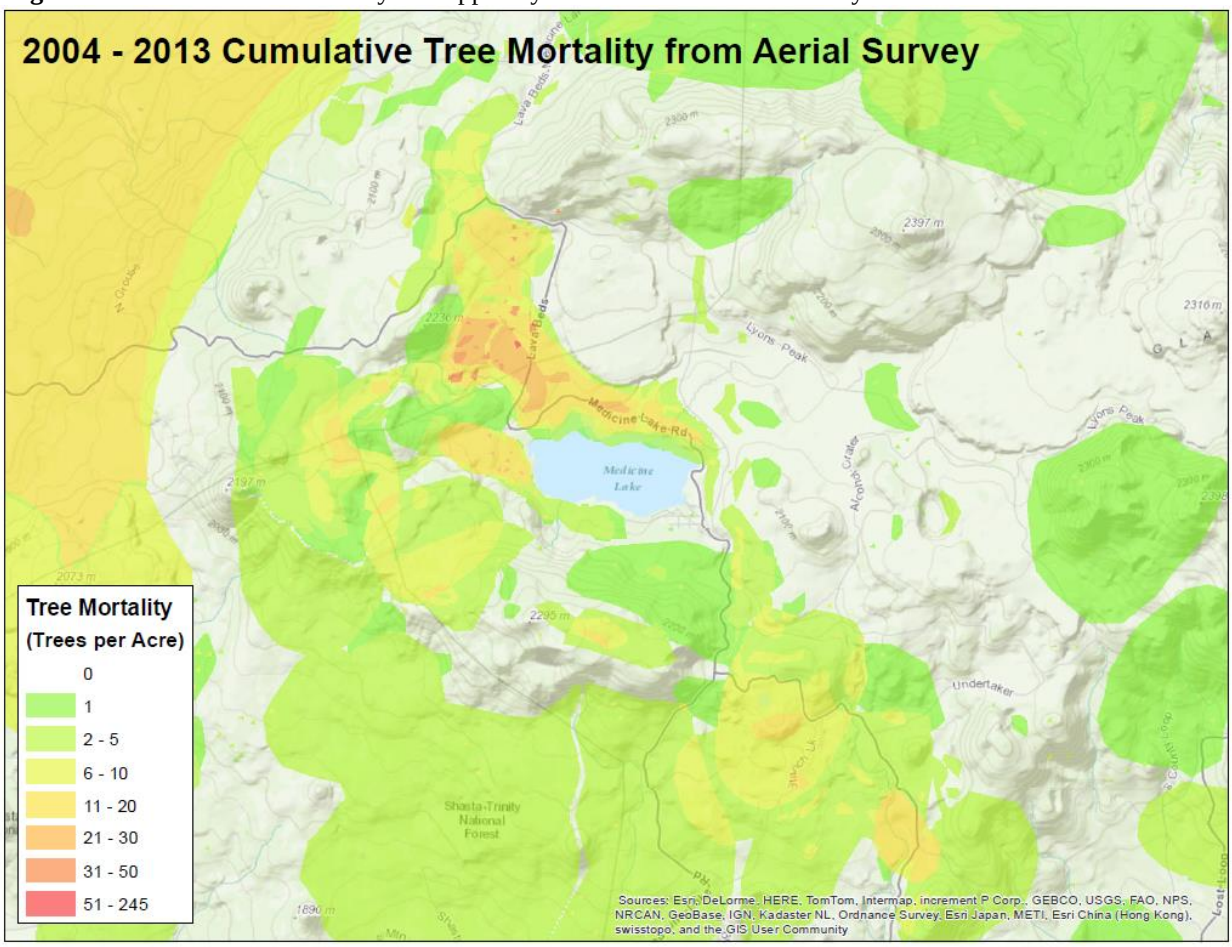
Stand #	LPPA > 9"	Hazard Rating
6100016Agg1	102	High
6100025	73	Moderate
6100040	121	High
6100110	141	High
6100120Agg2	167	High
6100130Agg1	88	Moderate
6100140Agg1	115	High
6100150Agg1	78	Moderate
6100170Agg1	113	High
6100170Agg2	137	High
6100190	168	High
6100270Agg1	64	Low
6100400Agg1	87	Moderate
6110011Agg1	6	Low

Mountain pine beetle-caused mortality during the current outbreak

Since 2005, a mountain pine beetle outbreak has killed thousands of LPP across the Medicine Lake caldera, especially in the northwest corner and in areas around the lake (Figure 2). The level of mortality has varied slightly by year with most occurring between 2008 and 2012. The most impacted areas have lost a significant portion of the large diameter LPP component (Figure 3). MPB-caused mortality in the campgrounds and along roads has required the removal of hundreds of hazard trees and left several campsites devoid of shade. In an effort to minimize the number of MPB-attacked trees within campgrounds, green infested trees were continuously cut and removed beginning in 2011 (Figure 4). These treatments were combined with the application of anti-aggregation pheromones to campground trees. After mixed success and continued tree mortality, a decision was made to apply insecticides to high-value campground trees in 2013.

The level of mountain pine beetle activity declined in 2013 and again in 2014 despite the majority of stands remaining in a high hazard condition (i.e. high numbers of larger diameter LPP). The decline is suspected to be related in part to extreme cold temperatures in early January and early December 2013, both events following warmer than average fall temperatures. First and second instar MPB larvae likely had not built up cold tolerance due to warm fall weather and were therefore vulnerable to abrupt extreme freezing temperatures. Dead larvae were observed in nearly all trees that were inspected in the spring of 2014 following the December 2013 event.

Figure 2. Cumulative tree mortality as mapped by FHP Aerial Detection Survey.


2004 - 2013 Cumulative Tree Mortality from Aerial Survey
Tree Mortality
(Trees per Acre)
0
1
2 - 5
6 - 10
11 - 20
21 - 30
31 - 50
51 - 245
Medicine Lake Rd
Medicine Lake
Lava Beds
Lyons Peak
Undertaker
Shasta-Trinity National Forest
Sources: Esri, DeLorme, HERE, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Mountain pine beetle outbreaks have also occurred over the same general time period in other northeastern California and southern Oregon LPP forests. These areas experienced very high levels of mortality, losing most of the larger diameter LPP component before outbreaks subsided. Mountain pine beetle outbreaks in south-central Oregon resulted in over 300,000 acres of LPP mortality. The Warner Mountain outbreak in Oregon and California is estimated to have caused the mortality of at least a couple million lodgepole, whitebark and western white pine (Figures 5 – 8).

Figure 3. Mountain pine beetle-killed LPP within the Caldera project area, Modoc NF (2011).

Differences between the Medicine Lake outbreak and other regional outbreaks

Stand conditions and prevailing weather patterns for all of these outbreak areas were very similar. All areas contained a large number of acres of high hazard lodgepole pine forest and experienced a similar warm and dry period beginning around 2000 and continuing to the present. Even though the lodgepole pine at Medicine Lake are in a similar high hazard condition, the mountain pine beetle outbreak has progressed much slower than in nearby outbreak areas and has not yet resulted in the same level of tree mortality. One possible explanation for the slower progression of the mortality could

be that local climate conditions are slightly less favorable for MPB within the Medicine Lake caldera. The topography of the caldera creates a cold sink where MPB populations are potentially subjected to more frequent and extreme cold temperature events, especially in the fall and spring months when MPB larvae are most vulnerable. These events may periodically impact brood success and reduce MPB populations. This appears to have occurred at least three times during the current outbreak.

Figure 4. Green infested LPP removed from Medicine Lake campgrounds (2011).

Figure 5. Mountain pine beetle outbreak at Campbell Lake, Fremont-Winema NF (2009). Dead lodgepole pines were removed along roads and campsites.

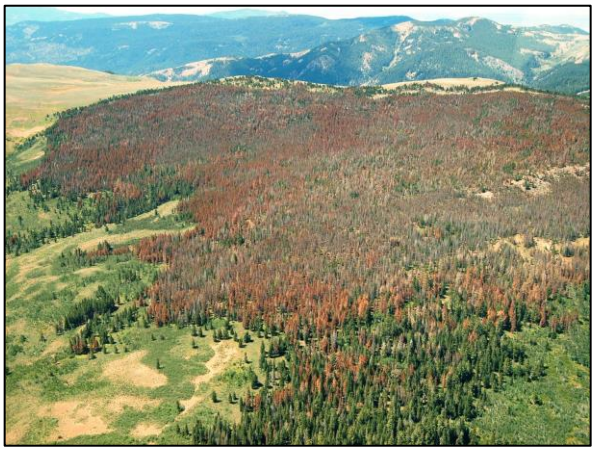


Figure 6. Mountain pine beetle outbreak in the north Warner Mountains, Modoc NF (2007). Nearly all larger diameter lodgepole pine were killed as well as many larger diameter whitebark and western white pine.

Figure 7. Mountain pine beetle outbreak in the south Warner Mountains, Modoc NF (2010) resulted in large areas of lodgepole and whitebark pine mortality.

Figure 8. Mountain pine beetle outbreak in lodgepole pine at Shovel Creek, Klamath NF (2007).

Mountain pine beetle larvae become extremely cold tolerant during the winter months and are able to survive temperatures down to -30°F unless sustained for several days. Winter temperatures in California seldom if ever reach these extremes for extended periods and likely have limited influence on MPB populations. Mountain pine beetle mortality is more likely to occur when cold temperature extremes are experienced during fall or spring. Studies from the

Rocky Mountain region suggest that early autumn or mid-spring temperatures of about 0°F can cause high levels of larval mortality. This is due to mountain pine beetle larvae slowly developing cold hardiness in the late fall and early winter and losing their cold hardiness early in the spring. Cold induced mortality events may have occurred in lodgepole pine stands at Medicine Lake in early April 2008 when temperatures dropped to -12°F. Cold induced mortality may have also occurred in late April 2011 when temperatures dropped to 3°F. Mountain pine beetle populations were rapidly increasing and observations of fewer attacked trees in 2011 compared to the previous year suggest that some beetle mortality may have occurred. However, the impact to the beetle population was short-lived as the number of attacked trees increased dramatically in 2012. The cold event in January 2013 (-20°F) would not have been expected to cause significant MPB mortality but the fall of 2012 was warmer than average from October through mid-December and may have prevented MPB larvae from developing adequate cold tolerance. It appears that the extreme cold temperatures that occurred in early December 2013 (reaching as low as -31°F) following a relatively warm October/November greatly reduced MPB populations throughout the Medicine Lake caldera. Early summer 2014 sampling of previously infested trees revealed large numbers of dead MPB larvae and belt transect surveys later in August revealed that only 1% of suitable hosts were currently infested. However, this survey only covered approximately about 2 % of the caldera and could have missed significant pockets of activity. Even though MPB activity was greatly reduced, green infested trees were observed in nearly every surveyed area, especially in areas most impacted by recent mortality.

Another potential explanation for the variation in MPB populations is that development appears to switch between semivoltine (one generation every two years) to univoltine (one generation per year) at Medicine Lake in response to annual fluctuations in average temperature. For example, the mountain pine beetle phenology model developed by Bentz et al (2014) using Medicine Lake temperature data predicts that the 2010 MPB generation was semivoltine while the 2011 generation was univoltine. This means that there should have been fewer adult beetles attacking trees in 2011 and more beetles attacking trees in 2012. This is consistent with PNW plot data at Medicine Lake where the number of attacked trees was 57 in 2010, 10 in 2011 and 47 in 2012. The potential for cold related MPB mortality and the potential for temperature related changes in MPB phenology are not mutually exclusive and may partially explain the observed population fluctuations at Medicine Lake during the current outbreak.

A third possibility is the relatively isolated location of LPP at Medicine Lake. This 5,300 acre LPP forest is >70 miles from large LPP forests to the north and east where recent MPB outbreaks have occurred. Areas ~ 6 miles to the west contain a few small LPP stands (~1,500 acres total) with minimal mortality while areas to the south are primarily mixed conifer. The caldera is also immediately surrounded by forests dominated by true fir that contain few MPB host species. Where other host species occur within these adjacent mixed conifer stands, such as western white pine and ponderosa pine, they are generally a minor stand component and not conducive for increasing MPB populations. In fact, these stands have very little evidence of significant past or present MPB activity (ponderosa pine mortality is more often attributed to western pine beetle, *Dendroctonus brevicomis*, attacks in these areas). It is likely that MPB populations fluctuate within the caldera with little migration from other areas.

Management considerations

The recent decline in the MPB population at Medicine Lake should be considered a short-term condition. High hazard stand conditions still exist in all areas and there is still a low level MPB

population distributed through the caldera. As has been observed with previous declines, such as in 2011, MPB populations can return to high levels and cause considerable tree mortality in just a few years. Even though cold temperature events can periodically kill bark beetles at the local level, they cannot be relied upon to keep populations in check or to end outbreaks. In lodgepole pine forest, MPB populations are primarily driven by the number of suitable hosts and land managers must focus on reducing stand susceptibility by reducing the number of physiological mature trees and creating heterogeneity in trees size, age and density across the landscape.

Predicted climate change will likely impact trees growing in the Medicine Lake caldera over the next 100 years. Although no Modoc National Forest specific climate change models are available at this time, there is general consensus among California models that summers will be drier than they are currently. This prediction is based on the forecasted rise in mean minimum and maximum temperatures and remains consistent regardless of future levels of annual precipitation, which may be highly variable (Merriam and Safford 2011). The potential for increased temperatures may result in higher MPB reproductive success and increased moisture stress on LPP in the Medicine Lake area. Improving the resilience of stands to future disturbance events through density, size class and species composition management will be critical to maintaining a healthy forested landscape.

Treatment Alternatives

Do nothing: The no management alternative would leave most stands in a high hazard condition that could result in widespread MPB-caused mortality and the loss of most larger diameter LPP during future outbreaks. In addition, many western white pines growing within and/or adjacent to lodgepole pine stands could also be killed. After suitable host material is depleted, residual stands of scattered red fir, mountain hemlock and smaller diameter lodgepole and western white pine would remain and be at a low risk for bark beetle-caused mortality for at least a few decades. However, this alternative would also allow high fuel loads associated with tree mortality to remain on site creating the potential for catastrophic wildfire. This threat would be high while brown needles remain attached to dead pines, be reduced once needles are shed and then increase again as dead trees begin to fall. A fire burning in these types of fuel conditions has the potential to consume residual live conifers, spread to adjacent upslope red fir/western white pine stands and threaten the recreation area and adjacent private land.

Green infested tree removal: The removal of green infested trees could capture some of the economic value and reduce the MPB population providing that ALL green infested trees are removed over the entire area prior to the next beetle emergence (can be combined with the salvage of older dead to capture more economic value and reduce fuel loads). This is probably not a viable option due to the logistics of tree removal, the short timeframe for implementation and the high likelihood of failing to identify and mark all green infested trees within the caldera. Even if most green infested trees are identified and removed during the initial operation, all lodgepole stands would have to be continuously monitored to locate and remove additional attacked trees for the duration of the outbreak. Stands would still be in a high hazard condition due to high densities of large diameter trees and fuel loads may still be considered high in some areas depending on residual stocking. This type of treatment could reduce short-term tree mortality throughout the area but is not likely to prevent mortality over the long-term (Egan et al 2014)

Removal of all suitable host trees: Harvesting all lodgepole pine > 8" dbh within the caldera would effectively remove all suitable hosts and likely reduce all stand hazard ratings to low. This type of treatment would be effective for many years until radial growth of residual trees increased average stand diameter and increased the number of susceptible trees to hazardous levels. Low levels of MPB activity could occur in small dense pockets of 6 to 8" trees but these would be relatively isolated and not be able to spread due to limited brood success in these smaller trees and the lack of suitable hosts over most of the landscape. One major disadvantage of this type of treatment is that it is not likely to achieve sufficient stand heterogeneity. Similarly treated stands within the caldera will eventually reach high susceptibility at the same in the future, leading to another landscape scale MPB problem and the need for another large-scale treatment. Removal of all suitable host trees is also not likely to meet management objectives for wildlife and recreation within the caldera.

Green tree harvest to create heterogeneity (preferred alternative): Thinning lodgepole pine stands to reduce the number of large trees (> 9" dbh) and create a diversity of stand conditions based on age, size and density across the 5,300 acres of LPP within the Medicine Lake caldera is the best long-term strategy to reduce the likelihood and degree of negative impacts of any future MPB outbreaks. Having a variety of stand conditions across the caldera ensures that MPB susceptibility will only reach high levels in a few stands at a time, reducing the chance of widespread mortality. This also greatly reduces the scope of future thinning treatments that may be needed to reduce stand hazard. The recent decline in the MPB population provides an excellent opportunity to implement silvicultural treatments aimed at achieving these desired stand conditions.

Thinning in areas of pure LPP should emphasize species, age, size and spatial diversity to reduce hazard across the landscape (Fettig et al 2014). Treatments can include a variety of prescriptions such group selection, single tree selection, thinning through all diameter classes or thinning through larger diameter size classes that are preferred hosts to MPB. Prescriptions in all thinning units should emphasize a reduction in the number of > 9" dbh LPP to below 100 trees per acre. Below this threshold, the number of larger trees can be varied to achieve heterogeneity between stands and but should be reduced to the lowest levels practical in each stand. If a reduction below this level cannot be achieved, a thin from below prescription that leaves residual large trees well-spaced may be an option. This type of thinning can change the microclimate of the stand, creating a less favorable environment for bark beetle pheromone communication. Opening up the canopy creates convection currents and air turbulence through increases in soil temperature as well as increasing wind speed (Bartos and Amman 1989, Amman and Logan 1998). This prevents bark beetle pheromone plumes from concentrating under the canopy and remaining in close proximity to individual trees or groups of trees. While this treatment option can be effective if use is restricted to a few locations spread out across the caldera, it does carry some inherent risk since the large tree component is retained and could sustain high levels of mortality should an outbreak occur.

Reducing the number of LPP that are heavily infected with dwarf mistletoe and retaining other species such as red fir where they exists will make thinning treatments even more effective in preventing future MPB-caused tree mortality. Stands within the campgrounds and other administrative sites could be managed for multiple size/age classes on each acre to ensure continuous forest cover over the long-term. Adjacent areas could have multiple size/age stands as well as even-aged units of various sizes/ages to maximize heterogeneity across the caldera.

It should be noted that reducing the basal area in dense even-aged stands in one entry can result in wind throw and/or snow breakage of residual trees. This is due to poor growing form and a lack of wind firmness of the residual trees. Therefore, desired stocking levels in these stands may be best achieved through multiple entries over time. Wind throw should not be a problem where larger trees have grown under more open conditions or were already in a dominant canopy position.

It is important to note that when implementing individual tree removal or stand thinning in a recreation area, it is required that all conifer stumps greater than 3" in diameter be treated with a registered borate compound (FSM R5 Supplement 2300-92-1 modified by FSH R5 Supplement 3409.11-2010-1) to reduce the probability of infection by *Heterobasidion occidentale* and *H. irregulare*, the causal agents of Heterobasidion root disease (formerly referred to as annosus root disease).

This alternative is aimed at balancing the need to immediately reduce stand susceptibility and create long-term resiliency to MPB while meeting other resource objectives. Treating lodgepole pine stands to create heterogeneity and reduce the number of larger diameter trees within the caldera should reduce the amount of tree mortality during any future outbreak. There is also a possibility that some outbreaks will be avoided due to the isolated nature of this lodgepole pine forest, the local microclimate and the large percentage of LPP acres treated. However, this type of treatment has inherent risks due to leaving susceptible hosts at various densities across the landscape and MPB-caused mortality may still reach levels that conflict with other resource objectives during future outbreaks.

Long-term monitoring is highly recommended to document MPB-caused mortality within various treatments at the stand level as well over the entire project area. Forest Health Protection can assist with the design and implementation of a monitoring plan. If you have any questions regarding this report and/or need additional information please contact me at 530-252-6431 or dcluck@fs.fed.us.

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Mountain Pine Beetle (Dendroctonus ponderosae) biology and ecology

Hosts: Lodgepole, ponderosa, coulter, knobcone, western white, sugar, and whitebark pines. Mountain pine beetle has also been found attacking Pinyon pine in southern California.

Distribution in California: Throughout the range of suitable host trees.

Identification: The adult is a black, cylindrical, medium-sized bark beetle (5 to 7.5 mm long). The egg gallery in the inner bark is long and straight, oriented vertically, and has a slight J-shape at the base. They range from 10 to 122 cm in length and are packed with frass. Larval galleries extend at right angles from both sides of the parent gallery. The sapwood of infested trees exhibits bluestain caused by fungi carried by the beetles. Pitch tubes are generally visible on the boles of attacked trees. On successfully attacked trees, these are small, red and numerous. Pitch tubes on unsuccessfully attacked trees are larger in size (around 2 cm in diameter), typically white, and widely scattered over the trunk. During drought years, infested trees may not produce pitch, and external evidence consists only of boring dust. These are referred to as blind attacks.

Effects: The mountain pine beetle ranks first in destructiveness among western bark beetles. In lodgepole pine, the mountain pine beetle attacks mature forests often over extensive areas. Attacks on other pine species may occur on either individual trees or groups of trees. Normally, the mountain pine beetle attacks trees that are under stress due to overstocking, or trees weakened by drought or disease. Periodically, large-scale outbreaks occur and infestations can extend into stands of healthy trees.

Ecological Role: The ecological effects of mountain pine beetle differ depending on the pine host being considered. In lodgepole pine, the mountain pine beetle is the key agent responsible for recycling older stands. When a lodgepole pine stand is about 100 years old, the mountain pine beetle infests the largest trees and within a 3 to 4-year period, may kill nearly 80% of the trees in the stand. The advanced regeneration and smaller trees are all that remain after a typical mountain pine beetle event in this host type. In ponderosa pine, the mountain pine beetle is generally associated with fairly young trees (75-100 years old) and acts as a thinning agent in denser stands. This thinning may be fairly irregular and may involve sizable groups of trees but is generally far less dramatic than is the case with lodgepole pine. In the case of five-needle pines where host trees are usually scattered among other tree species, the mountain pine beetle will create small holes in stands as it attacks pines stressed by competition, white pine blister rust, or other factors.

Life History: In California, the mountain pine beetle typically has one generation per year, but at higher elevations and more northern latitudes, there may only be one generation every two years. Adult flight occurs between June and October, peaking in late July and August for most locations. Females initiate attacks and release pheromones to attract males. Beetles create egg galleries in the inner bark and females lay eggs in niches along the side. The eggs hatch within 10 to 14 days and larvae begin feeding in the phloem. The winter is spent in the late larval stage and pupation occurs in the spring or early summer. By early-summer, callow adults form and new adults are ready to emerge shortly thereafter. Adults occasionally overwinter under the bark.

Conducive Habitats: The mountain pine beetle is generally associated with trees under stress from such factors as competition with other trees, infection by dwarf mistletoe, root disease organisms, or other pathogens, or infestation by other insects. During drought periods, all of

these factors become more important, and mountain pine beetle activity is at its greatest. In lodgepole pine, stands are highly unstable when they have 90-100 trees per acre that are greater than 9 in (22 cm.) in diameter. Second-growth ponderosa pine stands are likely to be infested when growth rates of codominant trees are less than ¾ in (19 mm.) in diameter for the last decade. Other species of pine are likely to be killed by mountain pine beetle when growing under dense stand conditions. Sugar pine infected with white pine blister rust or that have sustained fire injury are also highly susceptible to successful attacks.